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Workshop Report and Recommended Path Forward

Transboundary Water: Improving Methodologies and Developing Integrated Tools to Support Water Security

Dialogue toward a future framework for Federal coordination and integrated analysis capabilities in support of global water security

Raha Hakimdavar, Danielle Wood, John Eylander, Christa Peters-Lidard, Jane Smith, Brad Doorn, David Green, Corey Hummel, Thomas C Moore

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Executive Summary

River basins for which transboundary coordination and governance is a factor are of concern to US national security, yet there is often a lack of sufficient data-driven information available at the needed time horizons to inform transboundary water decision-making for the intelligence, defense, and foreign policy communities. To address this need, a two-day workshop entitled *Transboundary Water: Improving Methodologies and Developing Integrated Tools to Support Global Water Security* was held in August 2017 in Maryland. The committee that organized and convened the workshop (the Organizing Committee) included representatives from the National Aeronautics and Space Administration (NASA), the US Army Corps of Engineers Engineer Research and Development Center (ERDC), and the US Air Force. The primary goal of the workshop was to advance knowledge on the current US Government and partners' technical information needs and gaps to support national security interests in relation to transboundary water. The workshop also aimed to identify avenues for greater communication and collaboration among the scientific, intelligence, defense, and foreign policy communities. The discussion around transboundary water was considered in the context of the greater global water challenges facing US national security.

Representatives from the different agencies and organizations present were surveyed on issues related to the use of satellite remote sensing, hydrological and climate models and applications, and geospatial data in support of transboundary water related decision-making. Six generalized scenarios representing several transboundary water and global water security events that have occurred or are likely to occur in the future were presented to participants in breakout sessions to inform dialogue around needs and gaps. Through the breakout sessions and workshop discussions, it was found that many existing science and technology capabilities are already available that can address the operational information needs of decision makers on transboundary water, but the resources are often disjointed and not directly connected to end-user communities. There is also a lack of tools available that enable the translation and dissemination of the science and technology capabilities to decision-making processes. Overall, the US intelligence, defense, and foreign policy communities need to have a more comprehensive understanding of the role that water plays in specific current and future security scenarios. Finally, the lack of an operational center with a hydrologic forecasting requirement for global water resources and transboundary water presents a steep barrier for transitioning research and development activities to operations. Based on the workshop findings, the Organizing Committee has made several recommendations, which include:

1. Identify, document and assess the short-, medium- and long-term transboundary water information needs of the intelligence, defense, and foreign policy communities that can be fully or partially addressed through science and technology via an annual process of stakeholder engagement;
2. Increase collaboration between the Earth observation, hydro-climate modeling, and the intelligence, defense, and foreign policy communities to specifically set spatial and temporal requirements, identify data and information output formats that are useful for decision-making, and to reconcile the needs of the decision-making communities with the current and projected capabilities and limitations of the Earth observation and modeling communities;
3. Increase collaboration between the Earth observation and hydro-climate communities to specifically address challenges related to the integration of Earth observation data into models;

4. Implement training, education and outreach activities to support broader capacity development on existing technology and improve the research community's understanding of current and future needs; and
5. Develop a framework to disseminate key information from Earth observation data and corresponding models in an accessible and readily usable format for decision makers.

Following the recommendations, a path forward is laid out by the Organizing Committee, which includes engagement activities planned for 2018. Notably, a cross-agency working group and steering committee will be formed, dedicated to supporting the technical and institutional advancements required to fill knowledge and capability gaps on transboundary water, in the context of US national security. The group will also work to identify organizations that could accept the requirement to establish operational support for delivering the data needed to address global water security concerns, including those stemming from transboundary water.

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Acronyms

A5W – US Air Force Air Combat Command Weather Requirements Division

AFRICOM – US Africa Command

DIA – Defense Intelligence Agency

DOD – The US Department of Defense

EO – Earth observation

ERDC – US Army Engineer Research and Development Center

NASA – National Aeronautics and Space Agency

NGA – National Geospatial Intelligence Agency

NGIC – US Army Intelligence and Security Command

NGO – Non-government organization

NGS – National Geodetic Survey

NOAA – National Oceanic and Atmospheric Administration

ODNI – Office of the Director of National Intelligence

PACOM – US Pacific Command

SAR – Synthetic Aperture Radar

TRADOC – US Army Training and Doctrine Command

USACE – US Army Corps of Engineers

USAF – US Air Force

USAID – US Agency for International Development

USDA FAS – US Department of Agriculture Foreign Agricultural Service

USFS – US Forest Service

USGS – US Geological Survey

Preface

This report provides a synthesis from a workshop hosted by the National Aeronautics and Space Administration (NASA) and the United States Army Corps of Engineers (USACE). The workshop, entitled *Transboundary Water: Improving Methodologies and Developing Integrated Tools to Support Global Water Security*, was organized with the aim to connect the Earth observation and modeling communities with the intelligence, defense, and foreign policy communities on the current needs and capabilities for addressing global water security challenges, with a focus on transboundary water. Motivation for the workshop stemmed from a long-term collaboration on science and technology for water resources analysis between NASA and the US Army Corps of Engineers Engineer Research and Development Center (ERDC). In 2015, NASA and ERDC formed a working group to identify opportunities to improve support for transboundary water through analysis, prediction of disasters, remote sensing of hydrologic properties, and numerical studies of watersheds. The development of the transdisciplinary workshop was a product of this working relationship.

The workshop Organizing Committee included representatives from the ERDC, NASA Headquarters, NASA Goddard Space Flight Center, and the US Air Force. The meeting took place on August 15-16, 2017 in Silver Spring, Maryland, and pursued four broad objectives:

1. To examine the requirements of decision makers in the intelligence, defense, and foreign policy communities for knowledge derived from scientific and technical analysis related to transboundary water;
2. Discuss examples of capabilities provided by Earth science, Earth observation, geospatial data analysis, and advanced computing and visualization technologies that contribute to understanding transboundary water;
3. Identify gaps or barriers that limit the application of Earth science models, Earth observation data and geospatial analysis capabilities to inform decision support regarding transboundary water; and
4. Recommend approaches to reduce these gaps by proposing a framework for federal coordination on integrated analysis capabilities in the area of transboundary water, in support of global water security and US national interests.

This document presents: 1) a summary of discussions and findings from the workshop, and 2) the Organizing Committee's recommendations and proposed next steps based on the presentations and sessions held during the workshop and post-workshop synthesis activities. The major findings, shared principles and action-oriented recommendations are presented in the context of creating a national water security data and information framework. The intended audience for this report is threefold:

- Operational agencies and funders who will support the implementation process and initiatives put forth in this report;
- The community of scientific practitioners focused on Earth observation, modeling and the creation of decision support tools and their implications for global water security and management; and
- Policymakers for whom this document can inform their thinking and strategic approaches.

The recommendations and proposed activities in this report are based on the expertise and opinions of the Organizing Committee, and may not necessarily be reflective of the opinions of the broader group of participants during the workshop.

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1. Vision for the Workshop

A recent Intelligence Community Assessment report projected that over the next decade many countries strategically important to United States (US) national security will experience water-related challenges, contributing to the risk of instability and state failure, amid increased regional tensions.[i] Factors including climate change, population growth, increased frequency and intensity of extreme weather events, degradation of water quality, economic development and globalization can lead to strained access to water, affect resilience to natural hazard shocks, and impact overall human well-being. These factors can also lead to a rise in transboundary water disputes and potentially conflict.[ii] Managing transboundary water globally is significant, as nearly half the world is situated in one of 286 transboundary river basins, which hold 40% of the world's population and generate 60% of global freshwater.[iii][iv] Promoting cooperation on shared waters is also one of the four strategic objectives of the 2017 US Government Global Water Strategy, highlighting the timeliness of this topic for both the intelligence and foreign policy communities.[v]

As the US pursues foreign policy and security objectives to strengthen global peace and security, water resources are likely to play an ever-increasing role in defining the challenges and vulnerabilities that impact national security in the US. One of the limiting factors in understanding these vulnerabilities, in particular in transboundary water bodies, is the lack of readily available data-driven information to inform transboundary coordination, management, and governance. There is high potential for existing science and technology capabilities, particularly remote sensing-based Earth observation (EO) data and predictive models, to address information needs of decision makers regarding transboundary water, yet coordination across agencies and sectors is required to bridge capability and information gaps. To advance knowledge and identify a path forward on this work, the workshop *Transboundary Water: Improving Methodologies and Developing Integrated Tools to Support Global Water Security* was held with the vision to connect the EO and modeling communities with the intelligence, defense, and foreign policy communities on the current needs and capabilities for assessing global water security, through the lens of transboundary water. Five fundamental questions guided the transdisciplinary workshop:

1. How does an understanding of transboundary water challenges advance foreign policy and defense interests of the US?
2. What insights do the intelligence, defense, and foreign policy communities need on transboundary water to enable effective decision-making and planning?
3. What capabilities from Earth science, EO, and geospatial analysis are most relevant to informing decision-making by the intelligence, defense, and foreign policy communities on transboundary water?
4. What gaps and barriers limit the application of Earth science, EO, and geospatial capabilities to inform decision support regarding transboundary water?
5. What organizational and technical frameworks will foster integrated federal capabilities to support decision-making regarding transboundary water?

The workshop used a mixed format that featured speakers and discussion-based breakout sessions. Speakers from across the foreign policy, defense, intelligence, and science community provided contextual remarks, representing the US Department of States, the US Army, the US Air Force (USAF), the National Geospatial Intelligence Agency (NGA), US Pacific Command (PACOM), the Defense Intelligence Agency (DIA), the US Army Corps of Engineers Engineer Research and Development Center (ERDC), and the National Aeronautics and Space

Administration (NASA). The workshop also invited participants to engage directly during three breakout sessions, in one of six transboundary water related scenarios. The breakout sessions addressed the following transboundary water topics, in the context of global water security and US national interests:

- Coastal flood impacts to regional security;
- Cold regions hydrology;
- Famine and drought in eastern and southern Africa;
- International transboundary water impacts to regional security along the Pakistan-India border and the Nile River;
- International transboundary water impacts to regional security along the US-Mexico border; and
- River flood impacts to regional security.

These topics were designed to focus the workshop discussion around some of the important transboundary water-related challenges facing the US, and were not meant to represent a full range of regional and thematic priorities. In each breakout session, which included 10 to 20 participants, a facilitator and scribe led the workshop participants in a discussion reflecting the key objectives for the workshop in the context of their specific scenario. The breakout groups were provided with several paragraphs describing a geographic region, a transboundary water security challenge and potential stakeholders that face decisions. In response to these prompts, each breakout group addressed a common set of questions about the stakeholder needs, technical and scientific resources, and recommendations to reduce barriers to applying science and technology to inform decision-making. Participants were asked to evaluate each scenario, evaluate and/or further develop a list of end-user decision-making data or information needs and requirements, document existing capabilities of the research and operational communities that support those needs/requirements, and start to develop a list of gaps where new research should be undertaken to support their particular scenario.

In the following report, a brief workshop summary is provided through the lens of the five fundamental questions posed above. Key findings and recommendations based on outcomes from the workshop as well as post-workshop synthesis activities and discussions by the Organizing Committee are also provided. Finally, a path forward is laid out with concrete actions based on the findings and recommendations. It is noted that while the focus of the workshop was on transboundary water, many of the breakout sessions and discussions connected to the broader water security objectives of the US. In practice, “transboundary water” and “water security” can pose a very different set of challenges, solutions, and engaged stakeholders. Specific definitions for these terms were not provided during the workshop to allow more open dialogue and engagement between representatives from the different communities of practice.

2. Exploring Fundamental Questions

2.1. How does an understanding of transboundary water challenges advance foreign policy and defense interests of the US?

Workshop speakers outlined the need for their agencies to have a stronger understanding of transboundary water issues in order to inform their short- and long-term decisions. For example, having a greater understanding of the uncertainties around climate change, access to high-resolution and timely information, and overall strengthening of technical capabilities would lead to greater strategic future scenario planning for the defense community, and strengthen the capacity to avoid, prevent, or contain conflict. From the foreign policy perspective, EO data and models could support efforts among the various stakeholders involved with transboundary water cooperation and even in building institutional capacity.

The importance of transboundary water to US national security has also been documented by several recent reports, which the workshop speakers referenced. In its 2012 Intelligence Community Assessment, *Global Water Security,* the Office of the Director of National Intelligence (ODNI) strongly emphasizes that US security objectives will be impacted in the future as countries of interest to the US face challenges due to water shortages, declining water supply, difficulties in managing water and the need to coordinate transboundary water sharing.[i] The report specifically highlights river basins for which transboundary coordination is a key factor, while noting that several of these basins have limited or inadequate river management capacity. One of the reasons for these limits includes lack of hydrologic models and water flow measurements (among other hydro-met parameters) that can inform transboundary coordination. The 2017 *Global Trends Report* notes the complex relationship between water resources challenges and other features of society that are being impacted by climate change and contributing to social disruptions that can prompt state failures.[vi] In the report *Implications for US National Security of Anticipated Climate Change*, the National Intelligence Council more specifically notes that decreases in water and disputes over access to arable land will increase the risk of conflict between people who share river basins, aquifers, or land areas.[vii] The 2017 US Government Global Water Strategy, a coordinated effort between 17 federal agencies, states that one of the challenges to reducing conflict by promoting cooperation on shared waters is that data on disputed water systems are often sparse or not publicly available.[v]

Globally available datasets from EO and EO-informed models can be a critical tool for many security and negotiation scenarios, as data sharing is often a limitation in many water related disputes. Recognizing this, the workshop speakers stressed the importance of reconciling research-level capabilities with their decision support needs. Highlighting some of the current and future technical capabilities, speakers from the science community provided examples of federal research and development programs that are expanding skill in Earth science modeling infused with satellite-based EO and visualized with geospatial analysis tools to provide insight regarding water resources and water-related hazards. Many exciting technological opportunities were highlighted that could be used to assess transboundary water challenges, as was the need for greater federal coordination among relevant stakeholders.

2.2. What insights do the intelligence, defense, and foreign policy communities need on transboundary water to enable effective decision-making and planning?

During the workshop, various time horizons under which the defense and intelligence communities pursue decision-making were explored. The workshop discussion noted that different scientific and technical capabilities for hydrologic and meteorologic analyses are needed to inform short-, medium- and long-term decision horizons. For example, speakers addressed the need for long-term forecasts for potential trends in global water dynamics over 5 to 10 years that can inform scenario planning, policy direction, development priorities, transboundary negotiation and prediction of geographic regions that face increasing stress. This level of analysis was particularly relevant to decision-making at the level of Combatant Commands. Other speakers noted the need for medium-term hydrologic and meteorologic forecasts that inform near-term plans over months to several years to respond to challenges. Other stakeholders at the workshop noted that they need near-real time insights to inform decisions over days to weeks that impact the use of water by US military personnel, disaster response, protection of water infrastructure in conflict zones, and plans for personnel movements. The US Army Corps of Engineers (USACE) has the mission to provide hydrologic science capabilities that inform some of these medium- to short-term questions, but more coordination with end-user communities is needed in order to target the scientific methodologies.

Speakers highlighted broad needs for information about the state of water that benefits the defense, intelligence and foreign policy communities. This information covers all aspects of the water cycle, including weather forecasts, air and ocean temperatures, precipitation, reservoir storage, evapotranspiration, river flow, soil moisture and groundwater depletion. The speakers listed cold region information such as snow and ice cover, snow water equivalent and glacial coverage as priorities. Another category of information refers to phenomena enabled by water, such as crop health, crop yields and energy potential. The key water security issues highlighted in the meeting were:

- Flooding (resilience, response, and recovery)
- Water Supply (quality and quantity of water and impacts on agriculture, energy, and health)
- Navigation
- Environmental sustainability
- Military operations
- Drought and wildfires
- Interactions of climate, hydrology, and human impacts
- Treaty verification

In order to consider the water information needs of the intelligence, defense, and foreign policy communities with more specificity, the breakout sessions discussed classes of water-related scenarios in specific themes and geographic locations. Participants were asked to fully characterize the security concerns present in the particular domain that would need to be considered, the hydrologic data that would support situational awareness or understanding of the environment, as well as the impacts or other social or economic concerns. The scenarios were developed based on real "*reachback* support" requests that NASA and ERDC have been presented with over the past several years. *Reachback* provides the opportunity for agencies or units to reach outside of traditional avenues of information flow and utilize a broad array of sources to gather information to fill "gaps" needed for operational decision-making. Each scenario presented at the workshop was based on a potential reachback support request, and included an array of possible end-user decisions or information needs sought by the intelligence community, non-government organizations (NGOs), Army special operations advisors, and other organizations that directly or indirectly respond to transboundary water support situations or provide situational awareness. The decision maker information needs are summarized in Sections 2.2.1 to 2.2.6.

2.2.1. Coastal Flood Impacts to Regional Security

In the Coastal Flood Impacts scenario breakout session, participants were asked to consider specific vignettes related to coastal flood risks, from a national security perspective, and to identify the information needs and gaps to be able to better assess this risk and inform decisive actions. Appendix Table A1 provides an overview of the information needs of decision makers identified for this scenario. The participants in the breakout session on Coastal Flooding Impacts made several additional observations about the information needs of decision makers in this context. During flood events in populated areas, for example, it is helpful to have information at the scale of urban infrastructure. Government imagery from scientific satellites in passive visible imagery and active radar imagery is valuable for flooding events. Such imagery provides regional-scale information, but this may not be detailed enough to answer some questions about flood impacts. Methods are needed to integrate models with imagery and other measurements to provide more robust estimates of impacts. Additionally, the analysis of flood impacts should include impacts on agriculture and food security, while accounting for the stage of the crop calendar. Regions of interest were identified as: 1) coastal areas exposed to tropical or extra-tropical storms, 2) coastal areas impacted by riverine/estuary flooding, and 3) tsunami vulnerable coastlines. Specific examples of countries of interest included Korea, Haiti and the Philippines.

2.2.2. Cold Regions Hydrology

Participants in the Cold Regions Hydrology breakout sessions identified a number of security drivers and physical and environmental data needed for decision-making in these regions (Appendix Table A2). In addition to the vignettes proposed by the workshop organizers, participants in this session proposed focusing specifically on operations in the Arctic. Stated needs for this vignette included better models to forecast polar lows, modeling different mobility requirements important to the region, higher resolution sub-seasonal to seasonal sea ice predictions and better below-ice visualization. It was noted that there are technology differences for operating in the Arctic, such as instrumentation, field equipment and sensing capabilities/needs. Requirements for agency/services needed to inform decision-making was listed as follows:

- Coast Guard – Synthetic Aperture Radar (SAR) data, navigation information
- National Geodetic Survey (NGS) – Navigation charts and foundation data
- Navy – Sea-ice movement
- USGA – Ecosystem, environmental impact, coastal impact
- International agreements – Carbon sequestration, climate agreements
- Public health – Contamination in soils

Mobility and navigation in cold regions, and particularly in the Arctic region, was repeatedly identified as an important area of study and work, where sufficient information is not currently available and where EO and modeled data could be of use.

2.2.3. Famine and Drought in East and South Africa

Within the region, Lake Chad was identified as an important area for future consideration due to its importance as a shared water body, with seven countries bordering it. A number of other important regions vulnerable to drought and food security, and important to US national security, were listed. These other regions included Southeast Asia, Central America, Middle East and North Africa. Specific countries of concern were listed as Haiti, Jordan, Lebanon, Morocco and Tunisia. In addition to the information needs in Appendix Table A3, the following capacity building needs were shared:

- Development of better data discovery methods
- Recording of metadata (how was data collected, who collected it, etc.) to help with bias corrections and increase transparency

- More ground-based observations and social data collection (e.g. Food prices, household impacts) as well as knowledge of who collected the data
- Deepened partnerships on the ground to coordinate air efforts

One participant stated "we want to know who is impacted by the drought and where resources should go, not that there is a drought." In general, participants in this session recognized that there are many regions globally where drought and food security is or will be of concern in the future and that there is currently a disconnect between scientific knowledge and ground-based planning and response. Capacity building and better data integration were highlighted as ways of reconciling this disconnect.

2.2.4. International Transboundary Water and Regional Security at the Pakistan-India Border and the Nile River

The most important point stressed during this breakout session was the need for data integration and a centralized collaborative approach to information sharing. From a technical perspective, this could include better integrating social, economic, and political data with biophysical data, improving geospatial data integration and improving remote sensing and data assimilation of streamflow and other hydrological parameters. The transition from research to operation with predictable and sustained support as well as a formal consultation and needs assessment facilitated by organizations who could bridge the research and decision-making/operations sides were also listed as important considerations. A specific recommendation was made to co-design services with users and stakeholders, including a theory of change and stakeholder map at two levels: 1) high level including mandates and authority, and 2) technical and information flow among organizations. Table A4 summarizes additional information needs considered during the breakout session. The points made during this session are reaffirmed in a report by the Stimson Environmental Security Program, which found that there is currently no clear linkage between science and policy research in the Indus basin and only 12% of scientific studies have tried to develop a linkage between data and policy.[viii]

2.2.5. International Transboundary Water and Regional Security at the US-Mexico Border

Participants in this breakout session stressed the importance of data sharing between the two countries, yet highlighted the need to build trust. For this, a strategic plan with stakeholder ownership was recommended. In particular, it was noted that while detailed data may exist on the transboundary basins, there is not always easy access to this data. The establishment of trust and a mutual working relationship across sectors was thus identified as a priority area of focus for this breakout session.

2.2.6. River Flood Impacts to Regional Security

The greatest challenge for this breakout session was identified as the reconciliation of scale and spatial resolution between global datasets and regional flood impacts. The need for foundational base layers was highlighted as was the issue of data sparsity. For example, the difference between a 1-meter resolution model projection of streamflow and a 3-meter resolution model of streamflow can be significant from a decision-making standpoint.

The discussion in Sections 2.2.1 to 2.2.6 illustrates some of the rich combination of information that is relevant to decision makers in complex scenarios and the importance of targeted dialogue. While the summaries and Tables A1 to A6 provide a helpful starting point by listing the types of information needed, further analysis will increase the specificity of this analysis by identifying the specific quantitative requirements for the physical variables in terms of time frequency, forecast horizon and spatial resolution. Sections 4 and 5 aim to support this effort by putting forth a plan for more communication and exchange between the scientific and decision-making communities as well as the development of a targeted set of education and capacity building tools.

2.3. What capabilities from Earth science, EO and geospatial analysis are most relevant to informing decision-making by the intelligence, defense, and foreign policy communities on transboundary water?

Throughout the workshop, speakers and participants provided examples of existing decision support systems that harness data collection, modeling, data assimilation and data integration. Many of the existing scientific models providing water resources insight are the result of government research supporting federal and academic scientists. In order to organize the examples of existing Earth science models and EO data that are available, Figure 1 provides a generic value chain that categorizes the key functions involved with providing Earth science information.

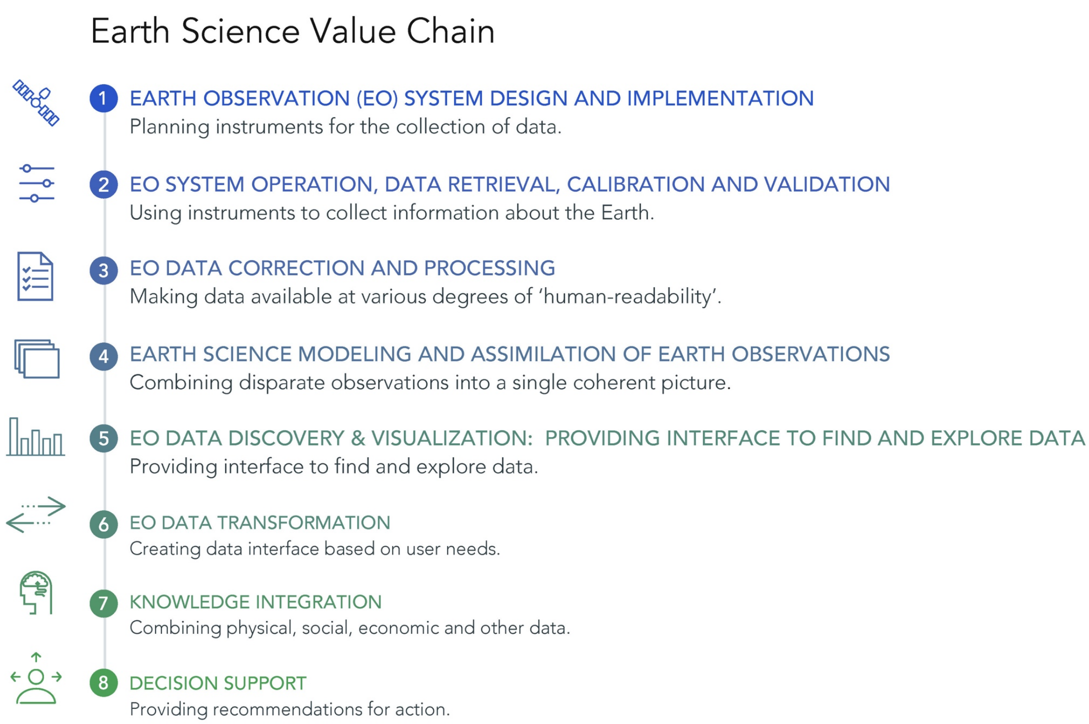

Figure 1 - Generic Earth science value chain highlighting the systems functions required to provide insight into water resources.

The first four steps emphasize the roles that are often played by government agencies or academic researchers to create the foundational observations, models and assimilated data products. Steps 5 to 8 are functions that are performed by many different entities, and represent the level at which most end-users access EO information, depending on levels of specialized knowledge and needs. In these later steps, there are a variety of approaches for moving an Earth science finding or EO to application and further creativity is needed to understand and facilitate this process. Steps 3 and 4 in Figure 1 reference Data Processing Levels 0 to 4. The satellite-based EO community uses these Levels to define the level of processing for a certain data product. The NASA Science Mission Directorate defines the data processing levels for EO data from satellites as follows.[ix]

- Level 0: Reconstructed, unprocessed instrument and payload data at full resolution
- Level 1A: Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information
- Level 1B: Level 1A data that have been processed to sensor units
- Level 2: Derived geophysical variables at the same resolution and location as Level 1 source data.
- Level 3: Variables mapped on uniform space-time grid scales, usually with some completeness and consistency
- Level 4: Model output or results from analyses of lower-level data

Value Chain Step	Examples of Tools & Capabilities
2 EO SYSTEM OPERATION, DATA RETRIEVAL, CALIBRATION AND VALIDATION	• SMAP https://smap.jpl.nasa.gov/ • SMOS https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/smos • MODIS https://modis.gsfc.nasa.gov/ • Sentinel-1 http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-1 • LANDSAT https://landsat.usgs.gov/
4 EARTH SCIENCE MODELING AND ASSIMILATION OF EARTH OBSERVATIONS	• NASA Goddard Space Flight Center's Land Data Assimilation Systems and Land Information System https://ldas.gsfc.nasa.gov/ NASA GSFC Modern Era Retrospective Analysis for Research and Applications https://gmao.gsfc.nasa.gov/reanalysis/MERRA/ • Global Ocean Data Assimilation Experiment https://www.godae-oceanview.org/ ADCIRC Circulation and Transport Models http://adcirc.org/ • USACE Coastal Storm Modeling System http://www.erdc.usace.army.mil/ Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476697/coastal-storm-modeling-system/
5 EO DATA DISCOVERY & VISUALIZATION: PROVIDING INTERFACE TO FIND AND EXPLORE DATA	• Air Force 14th Weather Squadron (SITREPS, Precipitation Monitoring/Warning, etc.) https://www.climate.af.mil/ • European Commission Joint Research Centre Water Portal http://water.jrc.ec.europa.eu/waterportal • European Commission Joint Research Centre Global Surface Water Explorer https://global-surface-water.appspot.com/ • Google Earth Engine https://earthengine.google.com/ • USGS Hydrosheds http://hydrosheds.cr.usgs.gov/index.php • Landsat Look http://landsatlook.usgs.gov/ • MODIS Rapid Response https://earthdata.nasa.gov/earth-observation-data/near-real-time/rapid-response • Global Flood Monitoring System http://flood.umd.edu/ • NASA IMERG Precipitation https://pmm.nasa.gov/category/keywords/imerg
7 KNOWLEDGE INTEGRATION	• Aqueduct Water Risk Atlas http://www.wri.org/our-work/project/aqueduct/ • NASA/USAID SERVIR www.servirglobal.net • USACE Reachback Operations Center https://redi.usace.army.mil • Dartmouth Flood Observatory http://floodobservatory.colorado.edu/
8 DECISION SUPPORT	• USAID/USGS/NASA FEWSNET www.fews.net • University of Colorado, Boulder's RiverWare http://www.colorado.edu/cadswes/creative-works/riverware

Figure 2 - Examples of existing science and technology capabilities, listed during the workshop breakout sessions, that are currently available to inform water related decision-making.

In the workshop breakout sessions, participants were specifically asked to identify the tools that are available to help characterize both the environmental concerns as well as the social, political, and economic concerns around water security and transboundary waters, specific to their scenario. Figure 2 provides examples of currently available Earth science capabilities in several key steps of the value chain, based on the breakout session discussions. The tools are categorized according to the highest value chain step that is relevant to each tool.

2.4 What gaps and barriers limit the application of Earth science, EO and geospatial capabilities to inform decision support regarding transboundary water?

A key motivation for the workshop was to highlight the opportunity to advance the use of existing Earth science modeling and observational products to inform decision-making related to transboundary water. The discussions at the workshop confirmed that barriers continue to limit the adoption of existing capabilities to the fullest extent possible. Even a small subset of the large number of available scientific tools to provide water related physical data (see Figure 2) can be daunting for potential data users. The examples provided in Figure 2 include a mix of research-based capabilities and operational systems. The research capabilities, such as those provided by or funded by NASA, often do not meet operational requirements of users. Instead, they represent the best effort of scientists to expand the state of the art. Research-based hydrology and meteorology tools are often referenced by operational decision makers, but they may not be vetted by a government authority that evaluates their quality. This can be a barrier to combining research-based and operational data products. From a scientific point of view, it is valuable to have multiple teams and organizations producing similar maps, models or data products in an ensemble approach (consensus building) to enable intercomparisons. For a non-science user, however, it is difficult to compare similar tools provided by different organizations to determine which meets their user needs. Figure 3, based on the workshop breakout session notes and post-workshop synthesis activities, demonstrates this point by providing an overview of the workflow required to translate EO and other spatial data to decision support products for operation, where data, technology and decision support tools are in most cases managed and operationalized by many different agencies. During the workshop, it was clear that there are opportunities to further support information sharing across federal agencies regarding the capabilities and research of different organizations. Currently, there is little integration between the leading agencies in Figure 3 that are at times working on the same or similar effort.

In addition to discussing barriers that limit the adoption of Earth science modeling and decision support for water resources, the workshop addressed the gaps in user needs that current science and technology do not yet address. For example, the breakout session on Coastal Flooding Impacts noted that there is a need to improve high-resolution bathymetry or topography data, ideally with 5-meter resolution. This group suggested that more work should be done to identify standard data formats that allow information from models to be transferred easily between organizations and across various systems. The flood community values high-resolution land use/land cover data across the globe. They also need to have high quality baseline data before a flood event in order to assess the severity of the disaster. Future work can improve water-related modeling and data collection for flooding by accounting for human actions during disaster response which may influence flooding risk or impacts, by seamlessly combining disparate data sources and by providing quantitative information about the level of uncertainty in model output or data products. This was also one of the critical needs of the River Flood Impacts breakout session. Timeliness of information was identified by stakeholders across the breakout sessions and throughout the workshop as being at least as important as accuracy, and thus tradeoffs are necessary to provide best information in the required time frame. Several participants stated that "scientists need to stop admiring the science" and rather target their work on the specific needs of the user-community. Table 1 provides an overview of the data and information gaps identified by breakout session participants. While this list is again a good starting point, more synthesis is required in order to better identify trends in data gaps across the different scenarios. For example, high temporal and spatial resolution rainfall would be a benefit (and is a need) for all of the breakout session scenarios, however it was only explicitly documented in two of the sessions. This highlights the need for continued stakeholder engagement to better identify decision-making needs.

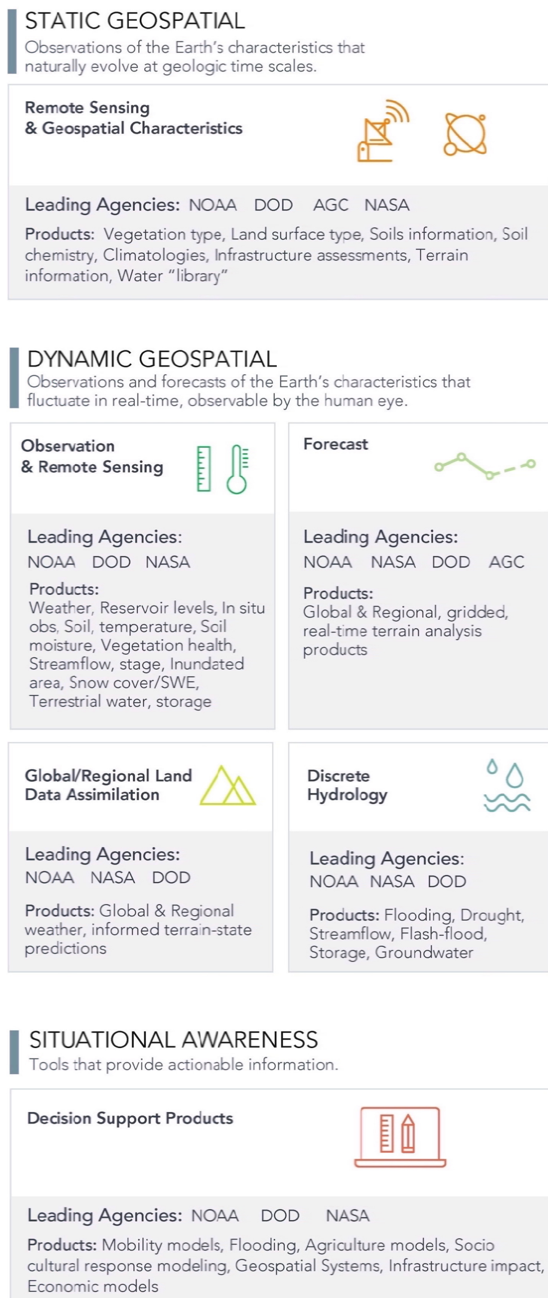

Figure 3 – Overview of the workflow required to translate EO and other spatial data to a decision support product. Data, technology and decision support tools are in most cases managed and operationalized by many different agencies.

Table 1: Data and information gaps explicitly identified in breakout sessions.

Topic/Subtopic	Gap identified in a breakout session	Session* 1	2	3	4	5	6
Atmosphere							
Precipitation	Rainfall rate (sub-hour)		■				■
	Seasonal rain and snow forecasts		■	■			■
	Climate teleconnections		■				
Models	Inclusion of complex terrain in atmospheric models						■
Terrestrial surface		**1**	**2**	**3**	**4**	**5**	**6**
H_2O	Water quality				■	■	
	Sea ice extent, freeze rates, and seasonality		■				
	(Rapid) Flood inundation scale and depth/elevation		■	■			■
	Data assimilation of stream flow				■		
	Combined base flood		■				
Land	Crop yield models			■			
	LIDAR data						■
	High resolution land use/cover data (global)	■					
Terrestrial sub-surface		**1**	**2**	**3**	**4**	**5**	**6**
	Aquifer location/depth/volume/flows			■			
	Bathymetry	■	■				■
	Groundwater flows/supply/quality		■		■	■	■
	Soils and terrain (e.g. for mudslide-type events)	■	■				
Integrated sub-surface/surface/atmosphere		**1**	**2**	**3**	**4**	**5**	**6**
Models/forecasts	Model coupling across disciplines (hydrology, meteorology, snow)		■				
	Ocean model		■				
	Combining of hydro with socio-cultural data and economic data				■		
	Drought forecasts			■			
	Water balance assessment					■	
Human component	Knowledge on infrastructure	■					
Data/information dissemination/repositories		**1**	**2**	**3**	**4**	**5**	**6**
Data storage	Framework to manage/archive information/data	■	■		■		■
	Integrated data systems for multiple uses					■	
Data knowledge	Significance of events relative to historical/baseline events	■				■	
	Analysis decision aids		■				
	Cross border data availability			■			
Topic: Data/model/analysis design		**1**	**2**	**3**	**4**	**5**	**6**
Workflows	Advancement of data/tools from research to operational			■	■		
	Defined process for evaluation and improvement						■
	Integration of decision support tool into decision-making process	■			■		
Design and use	Funding shortfalls		■		■		
	User/stakeholder engagement to design and test use cases				■	■	
	Interagency collaboration						■
	Formal consultation and needs assessments				■		
Technical design	Products for 60-90 degrees north and south		■				
	Higher spatial and temporal resolution models/data (e.g. elevation, atmosphere, hydrology)		■				

Integration of disparate data, models, and protocols	
Validation and uncertainty quantification	

1) Coastal flood impacts to regional security

2) Cold regions hydrology

3) Famine & drought in east and south Africa

4) International transboundary water & regional security at the Pakistan-India border and Nile River

5) International transboundary water & regional security at the US-Mexico border

6) River flood impacts to regional security

2.5. What organizational and technical frameworks will foster integrated federal capabilities to support decision-making regarding transboundary water?

Although robust hydrologic tools exist to inform project design and water management, these tools typically rely on data-driven approaches premised on ample streamflow observations and idealized design storm events (e.g. 100-yr 24-hr rainfall event). Stakeholders expressed a need for weather informed near real-time situational awareness in data sparse areas within ungauged basins outside the contiguous US. Decision makers require a level of global awareness with the ability to readily attain local precision. They also need context. In other words, they need to understand the relative magnitude of an event and its societal impacts, as opposed to merely knowing river stage and discharge. Stakeholders put a premium on timeliness. Timely information has value despite considerable uncertainty. What these stakeholders described is an inherently different class of problem from that of sizing a levee using a conventional watershed model. The fact that the Department of Defense (DOD) lacks an operational center with a hydrologic forecasting requirement presents a steep barrier for transitioning research and development activities to operations. Another challenge exists in making the hydrologic information accessible and comprehensible. Stakeholders want the information online and on-demand. They emphasized a need for unclassified datasets since they need the information to be sharable with partner nations and NGOs. But they also want the information pushed across all security enclaves to accommodate various workflows and inform sensitive compartmented analyses.

This integrated hydrologic capability may also harness science capability enabled by civil agencies such as NASA, the National Oceanic and Atmospheric Agency (NOAA) and the US Geological Survey (USGS). This integrated hydrology capability would complement the existing atmospheric modeling and forecasting capabilities and allow decision makers to account for both weather and hydrology as part of integrated analysis. Better pairing of data and services within an integrated framework requires standardized conventions. For example, delineating hydrologic basins to achieve near-global coverage of consistently sized and hierarchically nested sub-basins at various scales, supported by a coding scheme that allows for analysis of watershed topology. Additionally, hydrologically conditioned terrain and bathymetric datasets are needed along with consistent vector-based stream networks attributed with information related to hydraulic geometry and upstream-to-downstream connectivity.

3. Key Findings

Key findings in this report are based on outcomes from the two-day workshop.

Key Finding 1 - *The US intelligence, defense, and foreign policy communities need to have a more comprehensive understanding (than what exists today) of the role that water plays in specific current and future security scenarios.*

The US faces security challenges as a consequence of global water shortages, declining water supply, difficulties in managing water, and the need to coordinate transboundary water sharing. River basins for which transboundary coordination is a key factor often have limited data sharing and/or ground-based hydro-met monitoring programs, and detailed hydrologic models that can inform coordination. There is a need for a more integrated understanding of the current and projected challenges of transboundary water, as significant information gaps currently exist in this space.

Key Finding 2 - *Many existing science and technology capabilities are available to address operational information needs of decision makers regarding transboundary water management, but are often disjointed and not directly connected to end-user communities.*

Currently, there are breaks in the chains linking data to the information and knowledge needed to fully understand the complex linkages between water stress and socio-economic stressors leading to conflict and security challenges in transboundary basins. The intelligence, defense, and foreign policy user communities and scientific research communities are not in sync with each other in regards to properly identifying requirements and therefore developing the right capabilities to support the end goal. There are a number of barriers that limit the adoption of existing Earth science modeling and observational capabilities to the fullest extent possible for informed decision-making related to transboundary water. One such barrier is that water security related research capabilities often do not meet operational requirements of users. There must be better knowledge exchange and communication of needs between the decision-making and scientific communities so that the decision-making community is able to incorporate appropriate science into decision-making, while the scientific community is able to more clearly target output products for specific end-user communities.

Key Finding 3 - *There is a lack of tools available that enable the translation and dissemination of key EO and modeled information for integration into transboundary water and US national security decision-making processes, within required time horizons.*

For transboundary water security scenarios, decision-makers in the intelligence and defense realms typically require the following: (1) a level of global understanding of the situation, (2) the ability to readily attain information at local precision, and (3) information and data context. There are a large number of available scientific tools that provide water related physical data, yet the data in its raw format often limits application to time-sensitive decisions. There is a need for tools that bridge research-based capabilities with operational systems. Targeted tools that can bridge the divide between scientific research and operational use are a need for the water security/decision-making community. In developing these tools, it is important to consider the various time horizons under which the defense and intelligence communities pursue decision-making, which can at times be at odds with research based products.

Key Finding 4 - *Addressing the challenges around transboundary water evaluations for short-, medium- and long-term decision-making purposes requires a transdisciplinary approach and engagement across many different sectors.*

The data and tools needed to answer questions on transboundary water challenges often exist, although collected by multiple agencies/entities across different scales of government and

NGOs for varying purposes. Since data, models and analysis tools are scattered across multiple platforms with different standards, much of it cannot be re-used beyond the primary purpose for which it was collected and is not used or ever transformed into information that supports real-time decision-making, identifying trends and patterns, or forecasting future conditions at a larger scale. The lack of this integrated solutions-based approach is identified as one of the key gaps facing the transboundary water and water security community. Broader collaboration across agencies, than what currently exists, is needed to support these activities.

Key Finding 5 - *Given the wide range of stakeholders that participated in the workshop, many would benefit from an integrated hydrological modeling, assimilation, forecasting and visualization capability hosted as an operational service that focuses on transboundary water and global water security, which currently does not exist.*

4. Recommendations

The workshop brought together a number of researchers and stakeholders with a broad range of expertise and needs. Based on common themes raised throughout the workshop and the key findings, the following recommendations are made to further progress the applications of Earth science models, EO and geospatial analysis to address transboundary water challenges.

Recommendation 1 - *Identify, document and assess the short-, medium-, and long-term water security needs of the intelligence, defense, and foreign policy communities that can be fully or partially addressed through science and technology via an annual process of stakeholder engagement.*

There is a need to have the policy, research, and operations communities fully engaged together to better understand how policy can be implemented and/or to inform new policy. There also needs to be broader collaboration across government agencies responsible for supporting transboundary water. Finally, there is a need for engagement with the broader water security community, through further exploration of interactions with the private sector, academia and the intelligence community that integrate scientific knowledge about water resources with other types of information regarding security, social, economic and health factors that impact US interests.

Recommendation 2 - *Increase collaboration between the EO, hydro-climate modeling and the intelligence, defense, and foreign policy communities to specifically set spatial and temporal requirements, identify data and information output formats that are useful for decision-making, and to reconcile the needs of the decision-making communities with the current and projected capabilities and limitations of the EO and modeling communities.*

It is critical to have direct stakeholder input into the design of the overall framework for transboundary water modeling, so that key requirements are documented and vetted, such as temporal latency, spatial and temporal resolutions, and output parameters and formats. One specific recommended activity is identifying opportunities within the member agencies to adopt the findings from the workshop to inform priorities for research and development in hydrologic and atmospheric modeling, assimilation, and decision support systems. Another is coordination across agencies to explore opportunities for further synchronization, such as between the Air Force Weather and ERDC, to enable global hydrology data to be discoverable and readily applied for decision support in concert with climate and ancillary water data.

Recommendation 3 - *Increase collaboration between the EO and hydro-climate communities to specifically address challenges related to the integration of EO data into models.*

While many institutional challenges are highlighted in this report, there also remain technical challenges that must be reconciled. Assimilation of real-time EO data into models is critical for improving accuracy forecasts and nowcasts of hydrologic processes. EO and hydrologic modeling groups need to come together to develop common formats, portals, and data standards to allow interoperability. Data assimilation techniques also need to be implemented in the models. For example, defining uncertainty in model predictions based on both input data and process calculations is critical for assessing risk and providing useful information to decision makers. Similarly, high-resolution data are required for critical physical components such as topography, bathymetry, and land cover, at a global scale. Also, improved resolution of meteorological, hydrological, and hydrodynamic processes need to be incorporated into the models to achieve spatial and temporal resolutions, as required by end-user communities. Technical collaboration across disciplines and sectors is viewed as a key activity in this regard.

Recommendation 4 - *Implement training, education and outreach activities to support broader capacity development on existing technology and improve the research community's understanding of current and future needs.*

There is a need for stronger engagement across all communities, supporting broader training and education on existing technology that may support current requirements (e.g. provide training on how to access existing datasets, strengths/weaknesses) as well for improving the research community's understanding of current and future needs of end-users. The most advantageous method for informing users and analysts of data and services that support hydrological decision-making is to have joint training forums where the operators, developers, and users are able to communicate and develop working relationships.

Recommendation 5 - *Develop a framework to disseminate key information from EO data and corresponding models in an accessible and readily usable format for decision makers.*

Transboundary water is a multidiscipline problem and requires integration of multiple models of physical processes, data, and decision support aids. Currently, no frameworks exist to seamlessly integrate the key information to make it easily accessible and usable for decision makers. Such a framework would have wide spread application to support a range of global water security issues. The development of a framework that integrates these components is needed for timely dissemination of data into decision support. This requires close coordination between key agencies. The overall need is to have decision support tools that include the integration of hydro-meteorological model outputs with social, cultural, economic, agricultural, infrastructure, and other information. This also requires that data sources and model results be made accessible through appropriate channels.

5. Path Forward

Four broad actions are identified by the Organizing Committee to guide the path forward. These actions are informed by the outcomes from the Transboundary Water Workshop, but, also address the broader goal of establishing a framework for federal cooperation to address the greater global water challenges threatening US national security, an important sub-set of which is the challenges specific to transboundary water. Initial activities are planned for early 2018. The proposed actions are summarized below.

1. *A **cross-agency working group** will be established, dedicated to supporting the technical and institutional advancements required to fill knowledge and capability gaps on transboundary water as well as a **steering committee** comprised of programmatic officials collaborating to support research and development planning*.

The key agencies critical to establishing and taking an active role in the proposed **cross-agency working group** include: (1) those directly involved in sponsoring and directing transboundary water research and development (e.g. NASA, USACE, USGS, NOAA), (2) those involved in operations (e.g. Air Force, Navy, National Water Center), and (3) those that have an end-use for the developed products beyond operation (e.g. US Department of State, USAID, DIA). An initial challenge posed to the cross-agency working group would be to establish a set of agreed upon definitions and boundaries for what constitutes transboundary water and global water security in the context of the greater US national security strategy. Additionally, the group would be called to develop a strategy for work prioritization (e.g. regional and thematic priorities) that would be in alignment with existing initiatives such as the US Government Global Water Strategy. A number of different avenues for establishing this group are currently being considered by the Organizing Committee, one of which includes expanding the current NASA-ERDC Transboundary Water Working Group to include other organizations and agencies interested in contributing to the research outcomes.

The **steering committee** is proposed to include: (1) representative teams and individuals from the federally-sponsored hydrology and climate research community that support transboundary water and water security capability development, and (2) representatives from research-based NGOs and universities that are conducting relevant research on the advancement of transboundary water dynamics in the context of global water security. While sponsored efforts from many of those in the research and development community have supported the creation of a number of tools addressing some aspects of transboundary water, these tools have not been systematically linked to support impacts-based decision-making. The challenge for the steering committee would be to establish linkages between currently disconnected areas of research and technology development so that watershed-level research can be scaled up to make global-level decisions and conversely global, regional and country-level research can be scaled down to make watershed-level decisions, when necessary. Additionally, the steering committee would need to identify opportunities, funding and otherwise, to promote cross-disciplinary collaboration, leading to the development of new methods for better integrating technological tools and capabilities into decision-making support tools.

2. *ERDC and NASA will jointly lead a dialogue series with a number of operational agencies in order to assess, in greater detail, the information needs of the intelligence, defense, and foreign policy communities, that could be met using EO and modeled data, and corresponding decision-support tools.*

The workshop highlighted some of the unique water security needs and requirements of a variety of agencies and organizations within the US Government and provided a good starting point to engage, learn and collaborate to deliver improved capabilities in support of better decision-making. More information on the specific needs and capabilities of the intelligence, defense, foreign policy and other end-user communities is needed to move forward. The first two recommendations in Section 4 outline an urgent need to utilize and expand on the existing technical knowledge base in order to better support the information needs of end-users. This requires a significant investment in further engagement with the respective communities in order to develop effective pathways to communicate and facilitate advances between organization representatives.

Those interested in water security data and decision support products are broadly categorized into three groups: (1) users of end products (e.g. PACOM), (2) data producers that use raw observational information (including weather observations and EO data) to generate a large number of datasets for downstream users (e.g. USAF 557WW), and (3) “data integrators” who combine several datasets to produce derived products for their end-users or integrate the data into enterprise software systems for use by a network of end-users and policy making groups. Beginning in 2018, ERDC and NASA will meet with organizations of each category in order to facilitate further dialogue through a series of structured and unstructured surveys. Based on our learning to date, a more detailed list of questions has been developed to help guide further interactions and learning events with representatives of organizations from each category. These draft questions and a more detailed plan for engagement is summarized in Appendix B. The end goal of this effort is to increase the effectiveness of the research-to-operations process, increase awareness of existing or developing technologies, and increase the opportunities for end-users to create more effective uses of capabilities and tools developed by research organizations.

3. *Existing capacity building and training tools will be assessed, combined and adapted to support the specific end-user communities identified in this report in the application of data stemming from EO and models into their decision-making processes. New training and capacity building activities may be developed, where existing tools are insufficient and unavailable to meet decision support needs.*

The workshop revealed that there are many existing decision support tools that are not currently being utilized or fully exploited by end-users. Lack of sufficient awareness and information access are two important factors in this disconnect. The path forward requires a full survey of the existing suite of decision support and capacity building tools available from the global community of subject matter experts that could be adapted and used to advance the capabilities of the end-users identified. The Organizing Committee is investigating the potential creation of a mechanism, under the umbrella of the cross-agency working group, to bring existing tools and trainings together as well as help to develop new integrated tools, where needed.

The Organizing Committee also proposes the development of a cross-organization transboundary water and water security education and training series that can better inform the user community about existing data and services. These sessions would also be used as a way for the scientific community to learn about capability gaps or shortfalls. The series would draw from existing trainings, such as those from the NASA Applied Sciences Program Applied Remote Sensing Training (ARSET) Capacity Building Program, and explore the development of additional programs or targeted trainings. The committee is also exploring offering trainings through short seminars at annual meetings and conferences where the operational community would meet, and organizing annual seminars hosted jointly by NASA and ERDC to train users on hydrology products.

4. *The cross-agency working group will identify organizations that accept the requirement to establish operational support for delivering the dynamic data needed on a daily basis for the US Government to better address global water security concerns, including those stemming from transboundary water.*

In support of Recommendation 5, an organization or combination of organizations need to be identified that could operationally deliver data and products supporting transboundary water and water security assessments. Currently, no center or combination of centers effectively exists to ensure decision makers have all the needed information for transboundary or water security-influenced decisions. For domestic operations, there are a number of agencies that support water security-related efforts, including NOAA's National Weather Service, the National Water Service, River Forecast Centers, USACE offices, Bureau of Land Management, various State organizations, and others. However, outside of the US, no organizations own policy or have a mandate to produce the suite of products required end-to-end to support transboundary or water security decision-making. The establishment of a central center or combination of centers, focusing on addressing global water security challenges from a technical and operation capacity is a critical need for the near-term future. The Organizing Committee hopes to use the momentum from the August workshop and future activities to advocate for the creation of this central hub.

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Appendix A – Information needs of decision makers identified during the six breakout sessions

Table A1: Information Needs of Decision Makers for Coastal Flood Scenario. Bulleted points in italics represent items originally proposed by the workshop organizing committee, while non-italic points are additional items proposed by breakout session participants.

Security drivers & operational concerns	**Physical & Environmental Data**	**Social, economic impacts & drivers**
• *Coastal port health and capacity* • *Location and affected industry along coast* • *Power generation* • *Coastal erosion and impact on infrastructure/navigation* • *Infrastructure capacity* • *Agriculture production & food security* • *Affected populations along or in floodplain* • *Military base locations and impacts* • *International agreements supporting mutual aid or aid response* • *Capacity to respond to disasters* • *Locations of gov't facilities in/out of coastal floodplains* • *Status of networks (transportation, water/sewer, communication, power)* • *Port security and accessibility* • *Potential for conflict* • *Timeliness of information*	• *Weather forecasts* • *Flood inundation area* • *Storm surge and wave analysis/prediction* • *Sediment loading/transport* • *Agricultural health and mapping* • *Water quality* • *Climatology* • *Variability/uncertainty of all products* • *Amount of recent change (versus historical climate records)* • *Links between inland and coastal hydrology* • *Pre and post disaster conditions* • *Movement of contaminants due to flooding* • *Flash flood risk and occurrence*	• *Built infrastructure capacity* • *Resource availability ($$)* • *Political desire & will to address drivers/concerns* • *Social desire & will to address drivers/concerns* • *Social capacity (education & training)* • *International aid agreements & partnerships* • *Economic status of individuals along affected paths* • *Insurance sector health* • *Internal capacity to supply aid* • *Temporary housing locations* • *Locations of industry in/along floodplains* • *Locations of social infrastructure (Hospitals; Gov't assistance centers; Police, fire, and rescue, etc)* • *Impacts of multiple related water problems causing cascading failures* • *Development level* • *Population displacement* • *Information sharing among stakeholders*

Table A2: Information Needs of Decision Makers for Cold Regions Hydrology. Bulleted points in italics represent items originally proposed by the workshop organizing committee, while non-italic points are additional items proposed by breakout session participants.

Security drivers & operational concerns	**Physical & Environmental Data**	**Social, economic impacts & drivers**
• *Mobility* • *River navigation/crossing* • *Training land impacts* • *Erosion (river & coastal) impacts on infrastructure* • *Construction challenges* • *Basing locations* • *Logistics (transportation of materials/supplies)* • *Energy (fuel, hydropower availability)* • *Hazardous material (unintended release of)*	• *Weather forecasts* • *Flood inundation area* • *Storm surge and wave analysis/prediction* • *Sediment loading/transport* • *Agricultural health and mapping* • *Water quality* • *Climatology* • *Variability/uncertainty of all products* • *Amount of recent change (versus historical climate records)*	• *Built infrastructure capacity* • *Resource availability ($$)* • *Political desire & will to address drivers/concerns* • *Social desire & will to address drivers/concerns* • *Social capacity (education & training)* • *International aid agreements & partnerships* • *Economic status of individuals along affected paths* • *Insurance sector health* • *Internal capacity to supply aid*

• *Flooding potential and flood inundation impacts* • River/ice dams (forecasting for ice jams) • Impact of permafrost thaw on infrastructure • Location and timing of oil spill on ice versus flowing river/ice • Inland flooding of freshwater (craters, sink holes, large depressions) • Coastal erosion from permafrost • Navigation issues	• *Links between inland and coastal hydrology* • *Pre and post disaster conditions* • *Movement of contaminants due to flooding* • *Flash flood risk and occurrence* • *Ice flow* • *Water/ice extent* • *Polar lows* • *Permafrost extent* • *Freshwater inflow/runoff* • *Water suspension* • *Ice thickness and deformation* • *Groundwater hydrology* • *Fine resolution observations and models* • Observation proxies • Soil contamination • Sea ice extent • Freeze rates and seasonality • Ocean circulation information • Detection of oil through ice and visualization of the location of the oil (radar capabilities)	• *Temporary housing locations* • *Locations of industry in/along floodplains* • *Locations of social infrastructure (Hospitals; Gov't assistance centers; Police, fire, and rescue, etc)* • *Impacts of multiple related water problems causing cascading failures* • *Development level* • *Population displacement* • *Information sharing among stakeholders* • *Tourism* • *Fishing*

Table A3: Information Needs of Decision Makers for Famine and Drought in East and South Africa. Bulleted points in italics represent items originally proposed by the workshop organizing committee, while non-italic points are additional items proposed by breakout session participants.

Security drivers & operational concerns	**Physical & Environmental Data**	**Social, economic impacts & drivers**
• *Population migration and Displaced People* • *Government Instability* • *Internal and external conflict* • *International and Inter-agency coordination* • *Logistics of food aid delivery* • *Communications infrastructure* • *Agriculture production & food security* • *Military base locations and impacts* • *Capacity to respond to disasters* • *Locations of US and local gov't facilities*	• *Vegetation Indices* • *Soil Moisture* • *Precipitation* • *Evapotranspiration* • *Historical Context of physical measurements* • *Crop water balance models* • *Agroclimatology* • *Crop Mask* • *Crop Type* • *Crop Calendar* • *Soil type* • *Soil health* • *Indices of Ocean Temperature (ie El Nino and Indian Ocean Dipole)* • *Land Surface Temperature* • *Ambient Air Temperature* • *Wind Speed* • *Land Surface Model outputs, including backcasting* • Crop yield • Water use • Mapping small water bodies and ephemeral/temporal patterns	• *Population Access to food* • *Population Health* • *Level of Malnutrition in population* • *Market dynamics, linking livestock and food prices* • *Calendar for planting and harvesting* • *Public health status and threat of epidemics* • *Displace populations* • *Domestic and international response to food crisis* • *Household and national economic indicators* • *Trade: Food Import and export dynamics* • Who is impacted and what are the effects? • Social safety nets and aspects of insurance • Food prices and household impacts

Table A4: Information Needs of Decision Makers for India-Pakistan border. Bulleted points in italics represent items originally proposed by the workshop organizing committee, while non-italic points are additional items proposed by breakout session participants.

Security drivers & operational concerns	**Physical & Environmental Data**	**Social, economic impacts & drivers**
• *Mobility* • *River navigation* • *Water storage capability and capacity* • *Erosion* • *Infrastructure capacity* • *Agriculture production & food security* • *Groundwater availability and contamination* • *Irrigation sources* • *Well locations and depths* • *Hydroelectric power generation* • *International agreements regulating transboundary flow volume* • *Dam operations* • *Capacity to manage cascade of dams* • *Existing communications network—is there a working group, river basin organization, or existing network of people who already communicate on these issues?* • *Upstream and downstream demand* • *Dynamics of Twin Cities with shared water demands and divided by a border* • *Water Treatment Processes* • *Fisheries* • *River crossing*	• *Snow depth* • *Glacial coverage* • *Snow water content* • *River flow volume* • *Flood inundation mapping* • *Precipitation amounts* • *Snow coverage* • *Reservoir height* • *Weather forecasts* • *Soil strength* • *Crop health & yield forecasts* • *Sediment transport* • *Water quality* • *Climatology* • *Variability of all products* • *Amount of recent change (versus historical climate records)* • *Data resolution* • *Timeliness of product* • *Forecast versus analysis* • *Forecast length* • *Evapotranspiration* • *Water metrics at Basin and Watershed Scale* • *Sedimentary Quality* • Rainfall analysis and prediction • Crop model information/ agricultural data • Flood and drought potential	• *Built infrastructure capacity* • *Resources availability ($$)* • *Political desire & will to address drivers/concerns* • *Social desire & will to address drivers/concerns* • *Social capacity (education & training)* • *International aid agreements & partnerships* • *Technical capacity (potentially covered under social capacity, but we often discuss human and technical capacity as two different issues)* • *Tourism?* • *Nationalism/willingness to consider resource-sharing in times of limitation* • *Industrial influence on decision-making* • *Drought Mitigation Plans* • Demographics, population growth drivers

Table A5: Information Needs of Decision Makers for US-Mexico border. Bulleted points in italics represent items originally proposed by the workshop organizing committee, while non-italic points are additional items proposed by breakout session participants.

Security drivers & operational concerns	**Physical & Environmental Data**	**Social, economic impacts & drivers**
• *Mobility* • *River navigation* • *Water storage capability and capacity* • *Erosion* • *Infrastructure capacity* • *Agriculture production & food security* • *Groundwater availability and contamination* • *Irrigation sources* • *Well locations and depths* • *Hydroelectric power generation* • *International agreements regulating transboundary flow volume* • *Dam operations*	• *Snow depth* • *Glacial coverage* • *Snow water content* • *River flow volume* • *Flood inundation mapping* • *Precipitation amounts* • *Snow coverage* • *Reservoir height* • *Weather forecasts* • *Soil strength* • *Crop health & yield forecasts* • *Sediment transport* • *Water quality* • *Climatology* • *Variability of all products*	• *Built infrastructure capacity* • *Resources availability ($$)* • *Political desire & will to address drivers/concerns* • *Social desire & will to address drivers/concerns* • *Social capacity (education & training)* • *International aid agreements & partnerships* • *Technical capacity (potentially covered under social capacity, but we often discuss human and technical capacity as two different issues)* • *Tourism?*

• *Capacity to manage cascade of dams* • *Existing communications network—is there a working group, river basin organization, or existing network of people who already communicate on these issues?* • *Upstream and downstream demand* • *Dynamics of Twin Cities with shared water demands and divided by a border* • *Water Treatment Processes* • *Fisheries* • *River crossing* • Water quality due to agricultural runoff	• *Amount of recent change (versus historical climate records)* • *Data resolution* • *Timeliness of product* • *Forecast versus analysis* • *Forecast length* • *Evapotranspiration* • *Water metrics at Basin and Watershed Scale* • *Sedimentary Quality* • Land use and land cover changes • Growing cycles and growing conditions	• *Nationalism/willingness to consider resource-sharing in times of limitation* • *Industrial influence on decision-making* • *Drought Mitigation Plans* • Vulnerability assessment, determine adaptive shifts • Access to food, water, energy • Immigrant/transient (seasonality) population

Table A6: Information Needs of Decision Makers for Regional Security

Security drivers & operational concerns	**Physical & Environmental Data**	**Social, economic impacts & drivers**
• *Streamflow capacity* • *River navigation/crossing* • *Water storage capability and capacity* • *Erosion* • *Infrastructure capacity* • *Agriculture production and food security* • *Affected populations along or in floodplain* • *Infrastructure assessments (dam age/health, agricultural land impacts, bridge and road health, power generation, health of hydroelectric dams along flooded rivers)* • *Impacted industrial production facilities* • *International agreements supporting mutual aid or aid response* • *Dam operations* • *Gov't influence/control in region* • Navigation • Power generation • Crop health	• *Streamflow* • *Snow water content* • *Reservoir height* • *Flood inundation area* • *Sediment loading/transport* • *Weather forecasts (precipitation forecasts)* • *Agricultural health and mapping* • *Water quality* • *Climatology* • *Variability of all products* • *Amount of recent change (versus historical climate records)* • *Data resolution* • *Timeliness of product* • *Forecast versus analysis* • *Forecast length*	• *Built infrastructure capacity* • *Resource availability ($$)* • *Political desire & will to address drivers/concerns* • *Social desire & will to address drivers/concerns* • *Social capacity (education & training)* • *International aid agreements and partnerships* • *Economic status of individuals along affected paths* • *Insurance sector health* • *Internal capacity to supply aid* • *Temporary housing locations* • *Locations of industry in/along floodplains* • *Locations of social infrastructure (hospitals, gov't assistance centers, police, fire and rescue)* • *Transboundary migration laws* • *Willingness to accept refugees and migrant workers* • *Location of jobs*

Appendix B – Summary of stakeholder engagement plan

In order to better understand detailed user needs, we need to directly engage end-users and decision-making organizations, interact with these organizations, and work to gain a more detailed understanding of their needs by interacting through question and answer-based dialogues. This type of dialogue is important to help guide research and development community product development, understand the key capability gaps that need to be closed, and improve the communication between end-users and researchers. There are many end-user organizations that should be targeted, including but not limited to US Army PACOM, US Army AFRICOM, US Department of Agriculture Foreign Agriculture Service (USDA FAS), US Agency for International Development (USAID) and US Forest Service (USFS). These organizations are directly involved in supporting decision-making, and conduct studies or analyses to deliver data to commanders or directors direct use. Each organization may be directly involved in decisions conducted at either the strategic or tactical level. Strategic level decisions are those with longer timelines and/or impacting larger numbers of groups and organizations. Tactical decisions have shorter timelines and require faster response times. The goal is to ask detailed questions, some of which are included in the list below, to better understand the primary end-users in order to better understand their decision-making processes and understand their decision-making timelines. A sample of the types of questions we plan to ask, in order to understand their requirements and help develop documented requirements that could be sent to Air Force Weather, include:

Decision support

- What is the decision-making process?
- Who makes decisions? At what level are decisions made? What types of decisions?
- What are the available funds and sources to support this effort?
- How can we help better inform users of products/capabilities?

Technical capacity

- How are data/services currently obtained? From what sources?
- Does the agency develop additional products themselves?
- What type of software are used? Are geospatial systems used?
- What network do they operate on?
- What types of software are used?
- Is there any collaboration software used?

In addition, there are organizations oriented toward creating and updating policies, developing requirements documentation that direct development, integration and operations, and/or supporting diplomacy. Some of those organizations include the US State Department, US Army Training and Doctrine Command (TRADOC), US Air Force Air Combat Command Weather Requirements Division (A5W), HQ USAF Directorate of Weather and HQ US Army G-2 Weather Team. We need to better understand each organizations role in the establishing the policy and doctrine for various operations. For instance, what role does TRADOC play in establishing Army policy and doctrine for supporting hydrology-based risk analyses to operations. Who is responsible for US doctrine for overseas engagement on water security issues? How do we influence their decision-making with data/products to inform policy/doctrine decisions? What policy or doctrine established the methodology for Army operations in regions with water security concerns? What policies are the US State Department developing to support international transboundary water security issues? Is it possible to better connect the science and engineering community to policy makers in order to better inform policy decisions and policy making?

There are a number of data integrator organizations including but not limited to the National Geospatial-Intelligence Agency, Defense Intelligence Agency, Army Geospatial Center, USACE, and National Ground Intelligence Center (NGIC). These organizations are not end-users, rather they ingest data from primary sources combine with data generated by other producers and/or add unique information specific to that organization, and may further integrate the data into a geospatial mapping system for use by downstream users. These users are part of a larger decision-making process and do not directly represent decision makers. The following questions are aimed at the integrators:

Technical capacity

- What types of data do they use now to support hydrological needs/requirements?
- What are the primary sources of hydrologic data?
- What networks do they operate on?
- How do they receive training or information on hydrology products available from the operational and/or research community?
- Do they need gridded data as part of their data integration process? Are they using gridded data now, or just pulling down graphic data to support decision-making?
- If they are using gridded data, how do they interact with the gridded data?
- What are the limitations to using data?
- What types of computer systems do they operate on?

Organizations we have categorized as data generators include the US Air Force 557WW and Navy's Command Meteorological and Oceanographic Center. We need to better engage with producers to determine how to incorporate new science/technology into their operational processes. The following questions need to be asked:

Decision support

- How does each producer acquire new science? How do requirements flow through the organization in order to support new science/technology acquisitions?
- How do the producers send data out to end-users?
- Do they understand what their end-users do with the data once it leaves the production system?

Technical capacity

- What types of hydrologic products are they willing to support operationally?
- At what scale are they willing to supply data/products to end-users?
- What types of data do they have to initialize hydrology products?
- Who does the science/technology acquisition?

Finally, there are a number of NGOs that support water security, conducting research and supporting international development and diplomatic relations. Some of those organizations include (but not limited to) the World Bank, the Stimson Center, World Resources Institute and International Research Institute for Climate and Society (IRI). These organizations support studies and analysis on behalf of commercial and governmental organizations, are often involved in providing information to policy makers or international diplomacy and/or investment, and should be included in future.